Reprinted from Nature, Vol. 302, No. 5906, pp. 295-301, 24 March 1983

El Niño Southern Oscillation phenomena

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At intervals that vary from 2 to 10 yr sea-surface temperatures and rainfall are unusually high and the tradewinds are unusually weak over the tropical Pacific Ocean. These Southern Oscillation El Niño events which devastate the ecology of the coastal zones of Ecuador and Peru, which affect the global atmospheric circulation and which can contribute to severe winters over northern America, often develop in a remarkably predictable manner. But the event which began in 1982 has not followed this pattern.

"WHEN pressure is high in the Pacific Ocean, it tends to be low in the Indian Ocean from Africa to Australia." That is how Walker[1-5] described the large-scale climate fluctuations which he named the Southern Oscillation (SO). Studies during the past half century have confirmed that the SO involves far more than a seesaw in the surface pressure between the South-east Pacific High Pressure Zone and the North Australian–Indonesian Low Pressure Zone (Fig. 1). It is now viewed as one of the most striking examples of interannual climate variability on a global scale: over the tropical Pacific Ocean the SO is associated with considerable fluctuations in the rainfall, the sea-surface temperature, and the intensity of the tradewinds, and it has recently been correlated with droughts over India, with severe winter weather over North America[6,7], and with fluctuations of the averaged temperature of the Northern Hemisphere atmosphere[8].

Early investigators were unable to identify the physical processes responsible for the long-term memory of the atmosphere implied by the persistence, over several seasons, of anomalous conditions associated with the SO. Only in the late 1960s did Bjerknes[9-11] point out that the SO is closely linked with interannual sea-surface temperature variations in the eastern and central Pacific Ocean. He proposed that the ocean, which has a memory much longer than that of the atmosphere, is of central importance in the SO.

Sea-surface temperature anomalies in the tropical Pacific Ocean are primarily associated with a phenomenon known as El Niño. This term originally referred to a warm current that flows southward along the coasts of Ecuador and Peru in January, February and March. The current marks the end of the local fishing season during which sea-surface tempertures are low and the south-east trade winds are intense. (The trades drive the surface waters of the eastern Pacific westward (offshore) and hence induce the upwelling of cold nutrient-rich water near the coast.) In certain years, temperatures are exceptionally high during the warm season and continue to be so during the normally cold upwelling season (Fig. 2*a*). At present the term El Niño is reserved for those interannual events when anomalously warm surface waters cover not only the coastal zone of South America but also most of the tropical Pacific Ocean. These events have disastrous economic consequences for the fishing and guano industries along the South American coast.

The average period of the SO is 3 yr—spectra of variables such as the surface pressure in the tropical Pacific have a peak at a period of ~38 months—but the SO is so aperiodic that the time between successive El Niño events varies from 2 to 10 yr (ref. 12). It is for this reason that the phases of SO during which sea-surface temperatures are high and the surface-pressure difference across the tropical Pacific is low, are viewed as independent events referred to as El Niño–Southern Oscillation (ENSO) events.

A typical phenomenon

Data sets that describe El Niño–Southern Oscillation events are most reliable for the period since the Second World War. Of the nine events that have occurred since 1950 seven evolved in a remarkably similar manner. These events—Figs 2 and 3 show their temporal and spatial evolution—started as modest anomalies off the coast of Ecuador and Peru during the boreal spring (February and March) and then expanded westward until the entire tropical Pacific Ocean was affected 6 months later. The minor event of 1963 and the current 1982 event evolved differently because unusually warm surface waters first appeared in the central Pacific Ocean. The coast of South America was affected subsequently so that the phase of the atypical phenomena was very different from the phase of the more common events.

In the following description of a typical event the development is, for convenience, divided into three phases: a precursory phase that precedes the onset off the South American coast in the early spring; next a phase during which anomalous conditions grow; and finally a phase during which anomalous conditions decay and normal conditions return.

(1) Precursors. The westward tradewinds that prevail over most of the tropical Pacific Ocean converge on the North Australian–Indonesian Low Pressure Zone where the air rises and where there is considerable cloudiness and rainfall. The air returns eastwards at greater altitudes and sinks over the cold, dry South-east Pacific High Pressure Zone which is evident in Fig. 1. This zonal cell is known as the Walker Circulation[9]. One of the precursors of El Niño is an eastward displacement of the upward branch of the Walker Circulation, to the region between New Guinea and the dateline. This is revealed by surface pressure, wind and rainfall records[12]: starting in October and November preceding the onset of El Niño the surface pressure at Darwin, Australia, increases, the tradewinds west of the dateline weaken and surface waters near the dateline warm slightly; the rainfall over Indonesia starts to decrease but near the dateline the rainfall increases. This change in the Walker Circulation is also evident in the eastern Pacific Ocean where, at southern latitudes outside the tropics, Easter Island at 27° S–109° W for example, surface pressure starts to fall as early as August preceding the onset of ENSO.

These precursors over the western Pacific appear to be necessary conditions for ENSO events but are not sufficient conditions because similar atmospheric changes can occur even when no El Niño is imminent. During 1979 and 1980 for example, changes in the wind, sea level and rainfall west of the dateline were very similar to those observed during ENSO events but there was no such event over the central and eastern Pacific[13].

In addition to the zonal Walker cell, the atmosphere has a meridional Hadley circulation. Its salient feature is the Intertropical Convergence Zone (ITCZ) where the south-east and north-east trades meet. This narrow zonal band of rising air, cloudiness and high rainfall, which is often visible on photographs taken from satellites, migrates seasonally between 10° N approximately in August and September, and 3° N in February and March. A precursor of ENSO is a southward displacement of the ITCZ which, in the eastern Pacific, is close to or even south of the Equator during the early months of El Niño years.

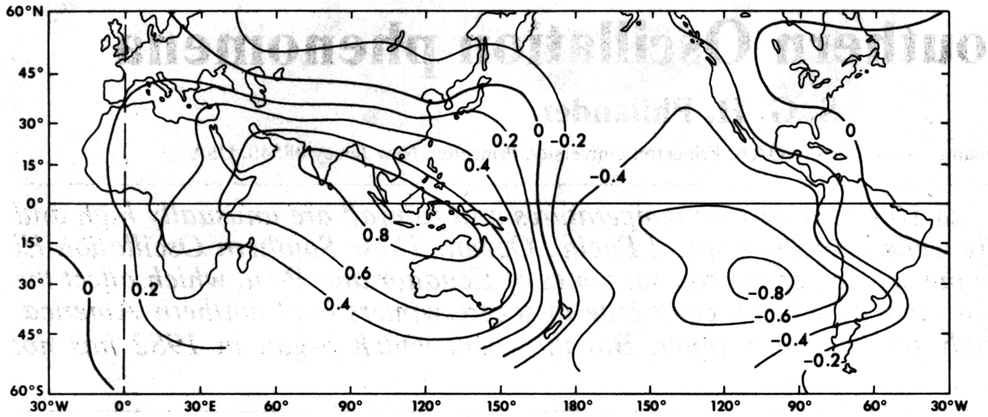
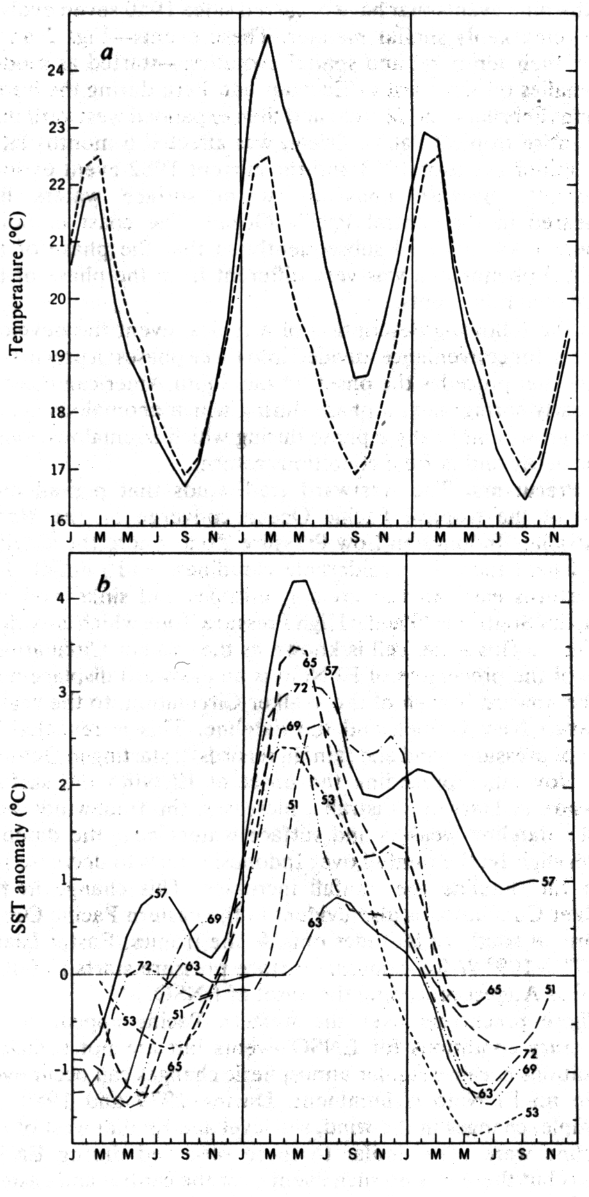


Fig. 1 The correlation of monthly mean surface pressure with that of Djakarta[45]. The correlations are large and negative in the South Pacific High Pressure Zone and are large and positive in the Australian–Indonesian Low Pressure Zone. The SO is not a standing oscillation so that correlations do not have a maximum at zero lag[46,47].



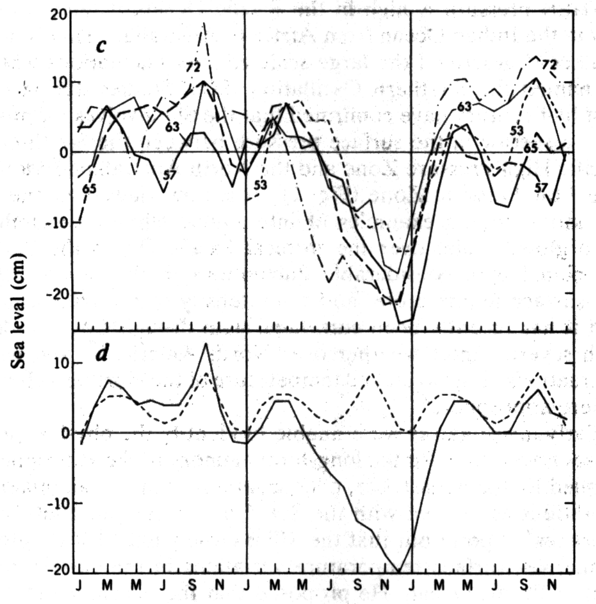


Fig. 2 *a*, Seasonal sea-surface temperature variations (dashed line) and sea-surface temperature variations during a typical ENSO event (obtained by averaging data for the events of 1951, 1953, 1957, 1963, 1965, 1969 and 1972) as measured along a ship track 100 km off the coast of South America between 3° S and 12° S. In the central and eastern tropical Pacific there is a high correlation between sea-surface temperature, sea level and depth of the thermocline, the layer of large vertical density gradients that separates the warm surface waters from the cold deep water of the ocean. *b*, Sea-surface temperature departures from the regular seasonal cycle during the ENSO events listed above, along the ship track that has been mentioned. The major 1976 event, not shown, was similar to the 1972 event. *c*, Sea-level variations at Truk (152° E, 7° N) during the indicated ENSO events[48]. These variations are representative of variations in the western tropical Pacific Ocean where sea-surface temperature changes are small and sea-level fluctuations are highly correlated with fluctuations in the depth of the thermocline. *d*, The average sea-level changes for the ENSO events in *c* (solid line) and the annual variations for years excluding ENSO events (dashed line) at Truk[48].

This displacement of the ITCZ[14,15] is associated with weak winds, unusually high sea-surface temperatures and a deep thermocline in the southeastern equatorial Pacific Ocean[16–19] These changes occur early in the calendar year when sea-surface temperatures and the depth of the thermocline in that region are already at a seasonal maximum, when the intensity of the south-east tradewinds has a seasonal minimum, and when the seasonal migrations of the ITCZ take it to its lowest latitude. ENSO during its early stages is therefore an amplification of the seasonal cycle (Fig 2*a*). In the southeastern equatorial Pacific the changes before and after the onset of ENSO are so similar that it is a matter of definition deciding when the precursors end and ENSO starts.

(2) The growth of anomalous conditions. The most striking feature of the second phase of ENSO is the westward expansion of anomalous conditions that first appear off the coast of Peru and Ecuador (Fig. 3). (The winds within 100 km of the coast of Peru remain normal throughout ENSO but are unrepresentative of conditions further offshore because of the presence of a low level atmospheric coastal jet[20].) Because of the westward

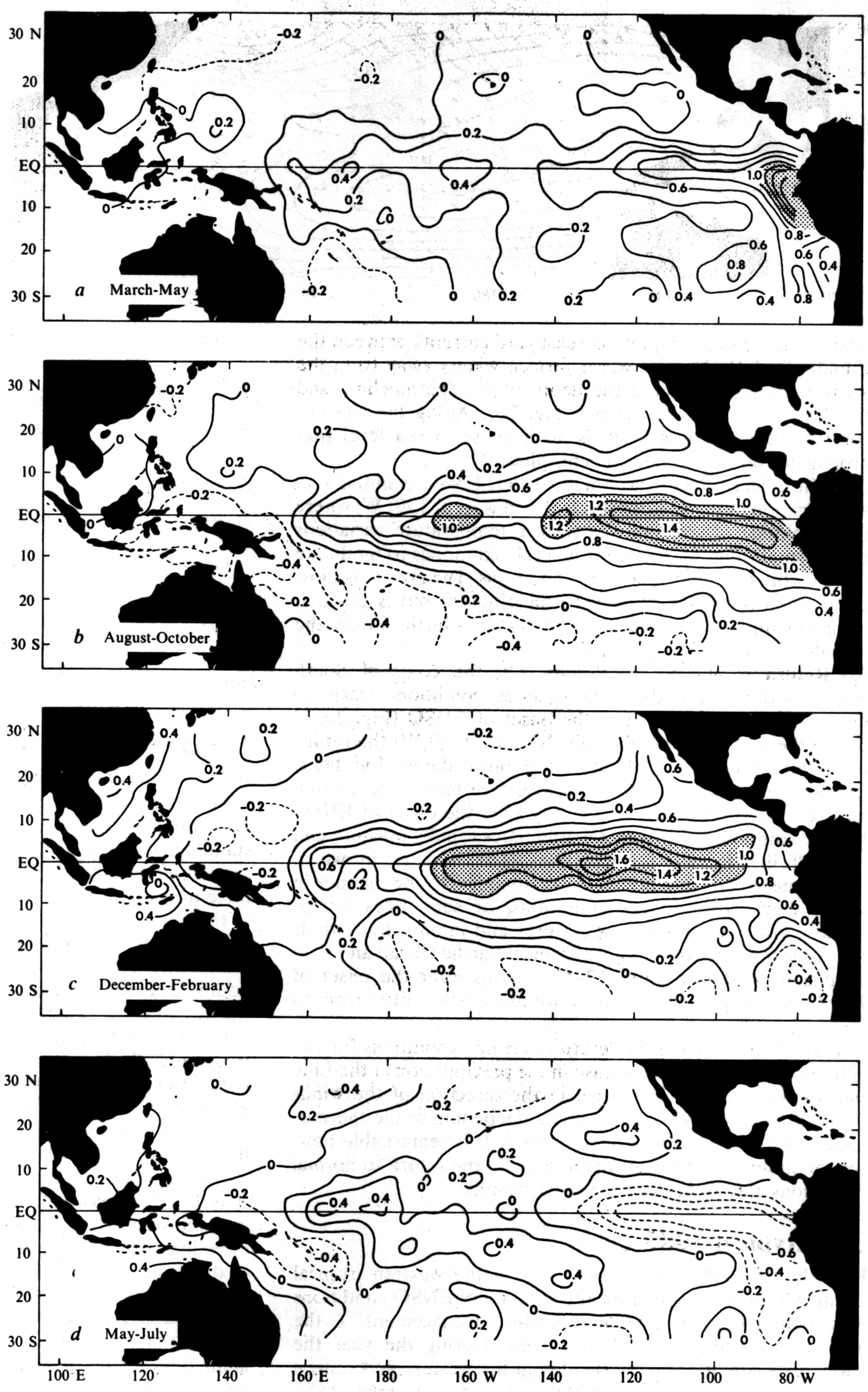


Fig. 3 Sea-surface temperature anomalies (in °C) during a typical ENSO event obtained by averaging data for the events between 1950 and 1973. *a*, March, April and May after the onset; *b*, the following August, September and October; *c*, the following December, January and February; *d*, May, June and July, more than a year after the onset[12].

propagation, at a speed between 50 and 100 cm s^{-1} exceptionally high rainfall and sea-surface temperatures at Christmas Island (2° N, 157° W) can be predicted several months in advance on the basis of data from the coast of Peru[21]. By October there are anomalous conditions over the entire tropical Pacific Ocean. While the anomalies propagate westwards, the precursors west of the dateline, described earlier, continue to grow in amplitude but their development lags behind the development of anomalous conditions to the east as is evident in Fig. 2 for example.

The Southern Oscillation–El Niño phenomenon is in its mature phase between November and January (after the onset) when there are unusually warm surface waters and exceptionally weak trade winds over most of the tropical Pacific Ocean, when the ITCZ is further south than normal[15] and when the Hadley Cell is intensified[22]. West of the dateline there are eastward winds which converge on the upward branch of the Walker Circulation which is now in the central Pacific Ocean. Rainfall in the central Pacific is exceptionally high, as is the temperature of the entire tropical troposphere. In the ocean, which is losing

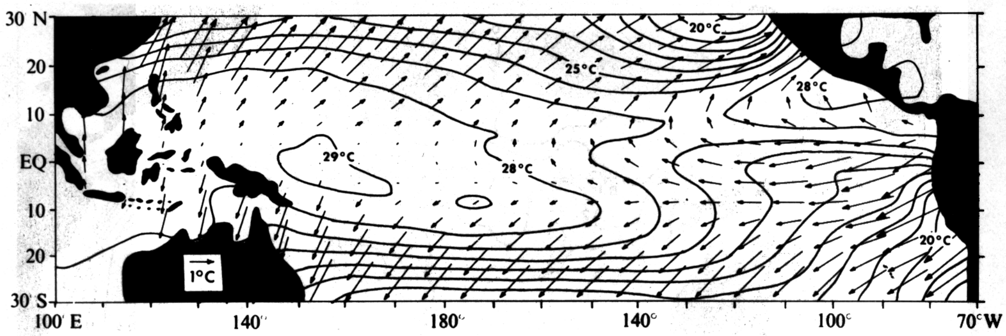


Fig. 4 Mean sea-surface temperatures (solid lines), and the amplitude (length of arrow) and phase (direction of arrow) of the annual cycle of sea-surface temperature in the tropical Pacific Ocean. Maximum sea-surface temperature is in January for an arrow that points downwards and in April for an arrow that points to the left.

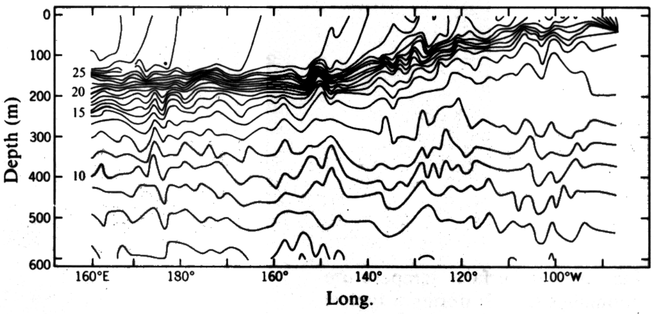


Fig. 5 Temperature (in °C) as a function of depth and longitude along the Equator in the Pacific Ocean[49].

heat to the atmosphere, intense eastward currents between the Equator and 10° N carry warm surface waters away from the western Pacific[16,23] where the depth of the thermocline, and the sea level, decrease sharply (Fig. 2*c*). Along the western coast of the Americas there is an increase in sea level that propagates poleward in both hemispheres[24,25].

In the eastern Pacific, as noted earlier, ENSO is initially an amplification of the seasonal cycle. Even west of 130° W, where the amplitude of seasonal sea-surface temperature variations is very small (Fig. 4), the seasonal cycle continues to modulate the growth of anomalous ENSO conditions. The growth is most rapid when the ITCZ is close to the Equator but is gradual, from July until September, when the ITCZ is furthest from the Equator[14,15]

(3) Return to normal conditions. Off the coast of South America the amplitude of anomalous conditions starts to decrease a few months after the onset of ENSO (Fig. 2*a*, *b*) but to the west of the Galapagos Islands (0° 90°W) the return to normal conditions does not start until almost 1 yr later. (Along the coast sea level and sea-surface temperature often have a second maximum in January after the onset of ENSO but the amplitude of this signal attenuates rapidly offshore and is small in Fig. 2*b*, for example). The manner in which anomalous ENSO conditions decay is similar to the manner in which they grow: normal conditions, or sometimes exceptionally low sea-surface temperatures and intense tradewinds first appear in the southeastern tropical Pacific Ocean and then propagate westward until, 12–18 months after the onset of ENSO, normal conditions are restored over the entire tropical Pacific Ocean.

West of the dateline the return to normal conditions follows a different timetable: a decrease in the precipitation at the Line Islands near 160° W, a change in the direction of the winds from eastwards to westwards, and a deepening of the thermocline, start in December and January[12]. It is remarkable how, for the different ENSO events in Fig. 2*c*, the return to normal conditions always starts in the same months.

The atypical 1982 event

In early 1982 anomalous conditions in the western tropical Pacific Ocean were similar to the precursory ENSO conditions described above, namely an eastward displacement of the ascending branch of the Walker cell. During the year the anomalous conditions grew steadily in the western and central Pacific Ocean so that there were, and as of November 1982 still are, severe droughts in Australia and Indonesia, heavy precipitation near the dateline, eastward rather than westward winds over the western Pacific and abnormally high sea-surface temperatures in the central Pacific Ocean. These unusual conditions were confined to the western and central Pacific until the early autumn. Only then did the sea-surface temperature start to increase in the eastern tropical Pacific Ocean. The current El Niño, unlike the more common ones, was therefore not an amplification of the seasonal cycle in the eastern Pacific but was completely out of phase with this cycle.

During November 1982 conditions in the tropical Pacific Ocean were similar to conditions during the mature phase of a typical ENSO event. It will be interesting to see whether or not the further development of the current event resembles that of a typical event.

Explanations

Interactions between the ocean and atmosphere are of central importance during ENSO. Anomalous conditions in the ocean and atmosphere develop practically in phase. For an understanding of the phenomenon it is of value to study first two simpler problems: the response of the ocean to the observed meteorological changes; and the response of the atmosphere to the observed sea-surface temperature changes.

(1) Response of the ocean. In the tropical Pacific Ocean the sea-surface temperature has a minimum along the coast of South America and increases in both a westwards and northwards direction (Fig. 4). These temperature gradients exist below the surface too (Fig. 5) and are maintained by the tradewinds. If the winds should stop blowing altogether then a horizontal redistribution of heat will cause horizontal density gradients in the ocean to weaken considerably. In low latitudes this can happen within a matter of weeks or months because the speed of the waves that effect the oceanic adjustment to a change in wind conditions increases with decreasing latitude[26]. It is for this reason that the intense Somali and equatorial undercurrents in the Indian Ocean, where the monsoons reverse direction, can be generated seasonally, whereas it would take of the order of a decade to generate the Gulf Stream[27] (which is at a much higher latitude) from a state of rest.

The weakening of the tradewinds during ENSO will reduce evaporation from the ocean but this cannot explain the anomalously warm sea-surface temperature because the ocean loses an unusually large amount of heat to the atmosphere during ENSO. The exceptionally warm surface waters are apparently caused by a rapid horizontal redistribution of heat in the upper ocean in response to the relaxation of the winds over the Pacific Ocean during ENSO[16,17]. Several mechanisms, whose relative importance changes during the development of ENSO, are responsible for the redistribution. During the early stages of a typical ENSO the weakening of the meridional component of the tradewinds in the eastern Pacific contributes to the appearance of unusually warm surface waters there. Normally the south-east trades which prevail to the south of the ITCZ cause coastal upwelling and low sea-surface temperatures along the South American coast, but cause downwelling north of the Equator (especially near 3° N) where

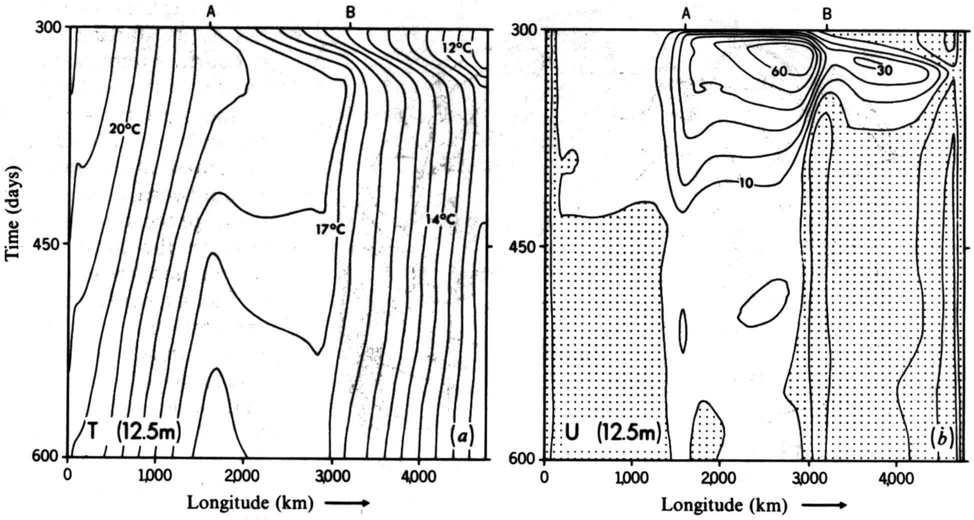


Fig. 6 The response of a numerical model of the ocean to spatially uniform westward winds of intensity 0.5 dyn cm^{-2} that suddenly cease to blow between meridians A and B. (The uniform winds had prevailed for 300 days by which time the model ocean was in a state of equilibrium and the most intense current was the subsurface equatorial undercurrent). The figures show changes along the Equator and near the ocean surface in *a* temperatures and *b* zonal component of the current in cm s^{-1}. (Motion is westward in the shaded region.) Note that the surface waters accelerate eastward temporarily, and become warm permanently, not only between meridians A and B but also in the region to the east[35].

sea-surface temperatures are high[28]. When the south-east trades weaken, warm water flows southwards near the coast. This happens seasonally in February and March[29], and also during most El Niño years[30]. Another factor that contributes to the appearance of anomalously warm surface waters is the weakening of the westward component of the trades. These winds maintain an eastward pressure force, which can be inferred from the zonal temperature gradients in the upper ocean (Fig. 5). When the winds weaken the pressure force is unbalanced and accelerates the warm surface equatorial waters in the west towards the east[31–35]. Figure 6 shows a simulation of this effect. The convergent eastward current, which can be observed seasonally in the equatorial Atlantic[36] and Pacific[34] during the boreal spring when the trades are weak, is augmented during a typical ENSO.

Figure 6 shows that the weakening of westward winds over a confined region will result in a warming not only of that region, but, because of eastward propagating equatorial Kelvin waves, also of the region to the east[18,33–35]. This warming in the east depends on the zonal extent of the region over which the winds weaken, the magnitude of the change in windstress, and the length of time for which the winds relax[35]. The amplitude of the changes in the western Pacific in 1982 were apparently sufficient to induce the appearance of exceptionally warm surface waters in the central and, at a later stage, in the eastern Pacific. The striking differences between the 1982 event and the more typical events which are characterized by anomalies that appear off the coast of Peru and then expand westward, suggest that the modest weakening of the tradewinds over the western Pacific during the precursory phase of a typical event is of secondary importance in the development of such an event. A comparison of conditions in the western Pacific in 1979 when a relaxation of the trades failed to induce El Niño in the east, and 1982 when an event occurred, should be fruitful.

Changes in the curl of the windstress also contribute to the redistribution of heat in the tropical Pacific Ocean during ENSO[16,23]. The curl drives the warm eastward surface current between 3° N and 10° N, and the cold westward current south of 3° N. During most ENSO events the wind changes in such a manner that the eastward current intensifies while the westward current weakens.

Sea-surface temperature changes during ENSO appear to be caused by the weakening of the tradewinds. The success[38] with which adiabatic models, forced with the observed winds, simulate thermocline displacements observed during ENSO, confirms this thesis. This, however, is not an explanation for ENSO because the weakening of the trades is part of the atmospheric response to the anomalously high sea-surface temperatures.

(2) The atmospheric response. Exceptionally warm surface waters result in an unusually large release of water vapour to the atmosphere which will be heated should the water condense. Horizontal temperature gradients in the tropical atmosphere are small so that heating of the lower atmosphere causes rising motion. (In mid- and high-latitudes on the other hand horizontal advection of cold air could balance the heating[39].) The rising motion causes the air in the surface layers to converge on the heated region. (The convergence pattern on a rotating globe is complex[39–43].) Suppose that westward winds are blowing over the heated region. In a downwind direction the air that converges on this region will weaken the westward winds. In an upwind direction the winds will be intensified. In other words, warm surface waters over the eastern tropical Pacific Ocean can cause a weakening of the tradewinds and can even cause eastward winds to appear over the western Pacific. There are, of course, factors other than high sea-surface temperatures that can cause westward winds over the western Pacific.

(3) Air–sea interactions. The arguments advanced above to explain the response of the ocean to anomalous winds, and the response of the atmosphere to unusually high sea-surface temperatures, can be used to determine the fate of a warm sea-surface temperature anomaly that appears in the equatorial Pacific. If the anomaly causes a local heating of the atmosphere then the tradewinds downwind from the anomaly will weaken. Sea-surface temperatures will rise in this region of relaxed winds, for reasons given above. Because of Kelvin waves, warm water will also be transported eastward back towards the original warm anomaly. It follows that this anomaly, in spite of losing latent heat to the atmosphere, will not only persist but will expand in a westward direction. The larger patch of unusually warm surface waters now has an even greater effect on the atmosphere and this in turn causes a further expansion of the warm anomaly. In these unstable air–sea interactions the westward expanding pool of warm water constantly feeds on the warmer water to the west. An anomaly off the coast of Peru, where the sea-surface temperature has a minimum (Fig. 4) will therefore readily expand westwards. It is more difficult for an anomaly in the western or central Pacific to expand eastward because two competing factors affect the sea-surface temperature to the east of an anomaly. One factor is the atmospheric convergence onto the warm anomaly. This causes an intensification of the tradewinds and hence causes enhanced equatorial upwelling and lower sea-surface temperatures. (Westward winds along the Equator induces divergent motion in the upper ocean.) The second factor that influences the sea-surface temperature is the weakening of the winds to the west of the anomaly which can cause a warming of the surface waters to the east as is evident in Fig. 6. Whether or not there is a net increase in the sea-surface temperature to the east of the anomaly depends on the relative importance of the two competing mechanisms. The factors which determine this relative importance, the intensity and shear of the tradewinds for example, require further study.

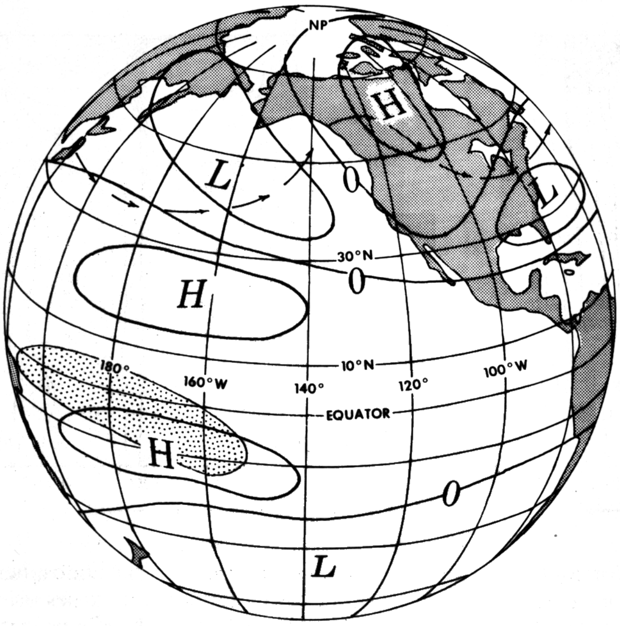


Fig. 7 Teleconnections to the extratropics during ENSO.

In this discussion it has been assumed that unusually warm surface waters heat the atmosphere locally but this is not necessarily so. Suppose that cold dry air descends on a pool of warm surface waters. The pool will lose latent heat to the atmosphere but the heating of the atmosphere will occur non-locally where the air rises and the water vapour condenses. For example, warm surface waters in the southeastern tropical Pacific Ocean where cold dry air descends during most of the year will alter the surface winds in the remote western Pacific where the moist air rises. The warm surface waters, instead of expanding because of the unstable air–sea interactions described above, will therefore disappear.

To grow, a pool of anomously warm surface waters must affect the atmosphere locally in such a manner that the altered surface winds induce warm oceanic currents towards the pool. This is possible when there is rising air over the pool, a condition which is satisfied in the southeastern equatorial Pacific Ocean when the ITCZ is in its southernmost position, in February and March. This is why the onset of a typical El Niño is always during the boreal spring, and why the subsequent growth of anomalous conditions continues to be modulated by the seasonal cycle. The interplay between the anomalously warm surface waters and the large-scale convergence of the surface winds is very complex because the pool of warm water, especially when it covers a considerable area can modify the large-scale convergence. This happens during the mature phase of ENSO, for example, when the ascending branch of the Walker Cell moves to the central Pacific. In a model of the unstable air–sea interactions described here, the rate at which anomalous conditions grow is sensitive to the relation between the sea-surface temperature and the local heating of the atmosphere. This relation is complex and at present is poorly understood.

The mechanisms that result in the growth of anomalous conditions during a typical ENSO are to some extent self-correcting. During the mature phase, the convergence of surface winds on the ascending branch of the Walker Circulation in the central Pacific is associated with an intensification of the trades over the eastern Pacific where sea-surface temperatures start to fall because of coastal and equatorial upwelling. The attendant reduction in the heating of the atmosphere moves the convergence zone westward so that the restoration of normal conditions gradually progresses in that direction. West of the dateline, as pointed out earlier, the return of normal conditions follows a different course for which there is no theory as yet.

The explanation for the development of ENSO given here has as its starting point the appearance of a modest warm sea-surface temperature anomaly in the eastern tropical Pacific Ocean, or the prolonged appearance of intense eastward winds in the western tropical Pacific. These initial conditions are precursors of ENSO and are associated with an eastward displacement of the upward branch of the Walker Circulation and a southward displacement of the ITCZ. An explanation for these precursors is likely to prove a formidable challenge because the locations of the regions of converging air are determined not only by factors in the tropical Pacific but also by factors elsewhere. Their seasonal migrations, for example, are part of the global seasonal cycle and the precursors of ENSO could be one aspect of an irregular global seasonal cycle. The eastward movement of the ascending branch of the Walker Cell, which was very important in the 1982 event, could be related to changes in the monsoons over the Indian Ocean. As the convergence zones control not only the initiation but also the subsequent development of ENSO a complete understanding of the phenomenon depends on identification of the factors that determine the position of the convergence zones.

Teleconnections with extratropical latitudes

Figure 7 depicts the global teleconnection pattern, at upper tropospheric levels of the atmosphere (heights of 5–10 km) during a Northern Hemisphere winter that coincides with the mature phase of ENSO when unusually warm surface waters cover a large part of the tropical Pacific Ocean. The region of enhanced precipitation in the central Pacific is shaded. The patterns marked H and L are the regions over which the surface of constant pressure at an altitude of ~5 km is anomalously high (H) or low (L). The high pressure over western Canada is associated with unusually low surface temperatures (at Edmonton, Alberta, for example); the low pressure over the southeastern United States is associated with unusually high surface temperatures at Charleston, South Carolina, for example. The arrows indicate how streamlines for airflow in the upper atmosphere are affected.

The correlations between indices of the SO, and certain North American meteorological variables are statistically significant[6,7,44] only for the Northern Hemisphere winter months of an ENSO year. Furthermore, the correlation coefficients are relatively low so that the tropical Pacific predictors account for less than half the variance of wintertime mean surface temperatures over western Canada for example. In practice this means that not all ENSO events are associated with a severe winter over North America—there was a severe winter during the 1976–77 ENSO event but not during the comparable 1972–73 event—and that exceptionally cold winters can occur even when there are no ENSO events, in 1978 and 1979, for example.

The heating of the tropical troposphere during ENSO events excites large-scale planetary waves in the atmosphere. The ray paths of these waves depend on the mean zonal winds[39] and can be such as to cause the perturbations shown in Fig. 7 provided eastward winds prevail from midlatitudes to the equatorial region where the heating occurs. This condition is usually satisfied during the Northern Hemisphere winter months which explains why the observed teleconnections exist in winter only.

Outlook

The available data sets provide a description of a typical El Niño–Southern Oscillation event—this is facilitated by the remarkable degree to which many events are similar—but the data sets are too poor to answer several important questions. Why do some ENSO events attain greater amplitudes than others, and why do some events affect the extratropics but other, comparable events do not? What is the role of anomalous heat fluxes across the ocean surface in the heat budget of the upper ocean? Does the time it takes the ocean to regain the heat lost to the atmosphere during ENSO determine when the next ENSO event can occur? To what extent is the Indian Ocean involved in ENSO? (Fig. 1 suggests that the Indian Ocean is involved.)

Data gathered over the past few years as part of the US programme EPOCS (Equatorial Pacific Ocean Climate Studies), which is a study of variability on interannual and shorter time scales in the tropical Pacific Ocean, are beginning to answer some of these questions. This programme will soon be complemented by an international programme that is now being planned.

During this work I benefited from discussions with Drs M. Cane, I. Held, P. Hisard, J. McWilliams, A. Oort and E. Rasmusson who provided preliminary data for the 1982 event.

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